Food and Agriculture Organization of the United Nations

Glaciers and mountains

The food, water security and livelihoods nexus

TECHNICAL BRIEF

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The food, water security and livelihoods nexus

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Matthew England, Sara Manuelli and Fabio Parisi
Food and Agriculture Organization of the United Nations

Food and Agriculture Organization of the United Nations

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Executive summary

This technical brief, published by the Mountain Partnership on International Mountain Day (IMD), is a contribution to the International Year of Glaciers' Preservation 2025. It provides an opportunity to raise awareness about the vital role of glaciers and other cryosphere components in supporting agricultural production, livelihoods and food and water security, both within mountain settings and downstream, and offers several important considerations for policymakers and practitioners.

Mountain glaciers and other cryosphere components are crucial for agricultural production, livelihoods and water and food security. About 70 percent of the Earth's freshwater exists as glaciers and ice caps, with meltwater making a significant seasonal contribution to river flows in cryosphere-dominated basins. A significant proportion of downstream-irrigated agriculture is reliant on glacier- and other cryosphere-fed mountain waters, especially in the dry season and during periods of drought. Globally, mountain water makes a substantial contribution to river flows annually, including cryosphere-derived meltwater. Almost 2 billion people are dependent on mountain water for food security.

Climate change is a major driver of cryosphere change, including the melting of glaciers. Mountain water flows are therefore becoming more uncertain and variable, affecting the quantity, timing and quality of water for agriculture. Climate change threatens water and food security and affects people's

Exploring glacial retreat on Fox glacier, New Zealand.

livelihoods in many ways, both in mountains and lowlands. It is also increasing disaster risk related to glaciers in many river basins.

Policy recommendations should aim to strengthen the resilience of mountain communities, farmers and herders; improve food and water security; and reduce disaster risks in glacier basins through measures that:

- strengthen early warning systems;
- improve data collection, as part of adaptation, monitoring, evaluation, learning and reporting;
- strengthen sustainable agriculture, water management and ecosystem-based adaptation approaches and practices;
- enhance governance and policy frameworks;
- promote transboundary cooperation; and
- ensure the mainstreaming of gender in agricultural policies and plans.

Harnessing youth-led initiatives and combining Indigenous Peoples' knowledge with science can be valuable in guiding policies on protected areas and sustainable land use and in tackling water supply disruptions and hazards from melting snow and ice.

Introduction

Why glaciers matter for food and water security

Mountain regions cover approximately 27 percent of the global land surface and are home to around 1.2 billion people, or 15 percent of the world's population. Mountains are regions of high biological and cultural diversity, as well as centres of crop diversity, providing vital goods and ecosystem services to billions of people living in and around mountains and areas downstream. In developing countries, an estimated 648 million people residing in mountains live in rural areas, and half of them are food insecure (Romeo *et al*., 2020). Agriculture and pastoralism are the main activities in mountains, with terrace farming widely practised on the slopes (FAO, 2019).[1] Lying at the intersection of the water–climate–biodiversity nexus, mountains' critical role in sustainable development cannot be ignored (UNESCO, 2025).

Mountains play a unique role in the global water cycle, providing essential regulating services, including storage, flow regulation, aquifer recharge and sediment retention. The mountain cryosphere stores water in the form of glacial ice and snow during cold seasons,[2] releasing it during warmer seasons as a major source of freshwater for mountain communities and downstream users, especially valuable during the summer and dry periods (Adler *et al.,* 2022).

Mountains and glaciers are the water towers of the world. Mountain waters provide a substantial proportion of freshwater for agriculture, including irrigation, as well as for hydropower and power generation, drinking water, sanitation and industry (Viviroli *et al.,* 2007).[3] Mountain waters are vital for food and energy security for almost 2 billion people living in and around mountain regions and in areas downstream (UNESCO, 2025).

There are more than 274 531 glaciers within mountains and around the edges of the Greenland and Antarctica ice sheets (Randolph Glacier Inventory, 2025). Glaciers cover an area of around 700 000 km², storing about 170 000 cubic km of ice (Huss and Farinotti, 2012). The cryosphere on land currently stores around 70 percent of the world's freshwater in the form of ice and snow (Dorigo *et al.,* 2021).

As a result of climate change, mountain regions are warming more rapidly than the global average. Glaciers and the wider mountain cryosphere rank among the most climate-sensitive elements of the earth system and are undergoing rapid and largely irreversible changes due to pronounced warming. Impacts include accelerated melting of glaciers, increasing permafrost thaw, declining snow cover, more erratic snowfall patterns and an increased risk of hazards

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[1] The five production systems in mountains include irrigated agriculture, rainfed agriculture, pastoral livestock, agropastoral livestock and forestry or agroforestry.
[2] For the purpose of this technical brief, the mountain cryosphere is considered to consist of glaciers, snow cover, permafrost (frozen ground) and river and lake ice.
[3] Various sources contribute to river flows from mountains, including rainfall, snow and glacier melt and groundwater.

(Hock *et al.,* 2019), which include but are not limited to glacial lake outburst floods (GLOFs), flooding of agricultural fields, landslides and avalanches.

Accelerated glacier retreat and increased glacier mass loss have been observed in recent decades (Adler *et al*., 2022; Hock *et al*., 2019).[4] Locations where this trend has occurred include high mountain glaciers, large polar glaciers and the Greenland and Antarctic ice sheets. Five of the past six years have seen the most rapid glacier retreat on record globally (Kennedy *et al*., 2024). Between 2000 and 2023, glaciers lost 6 542 billion tonnes of ice (The GlaMBIE Team, 2025).[5] Often termed the third pole, the Hindu Kush Himalaya region's glaciers are expected to lose 30 to 50 percent of their volume by 2100 under a 1.5 °C to 2 °C global warming scenario (Wester *et al*., 2023). Glaciers in UNESCO World Heritage sites are melting at an alarming rate, with one-third of the sites set to disappear by 2050 (Carvalho Resende, 2022).

Glacier melt, declining snow cover, more erratic snowfall patterns and increasing permafrost thaw will have a significant impact on global hydrology, affecting water and food security in mountains and downstream (UNESCO, 2025). The timing, availability and seasonal distribution of water for both mountain communities and lowland populations will become more erratic, uncertain and variable (ibid, 2025). The average winter snowmelt runoff is projected to increase, along with spring flow peaking earlier in the year. In some glacier-fed rivers, summer and annual runoff have increased due to accelerated glacier melt. Glaciers that are beyond their 'peak water' will gradually supply less runoff as the ice mass shrinks, impacting seasonal water availability in the mountains and downstream.[6] It is projected that by the end of this century, runoff from glaciers in all regions will have declined beyond peak water. Melting glaciers and ice sheets have been identified as one of the largest contributors to sea level rise in the past decades (Hock *et al.,* 2019).

Increasing runoff variability in snow-dominated and glacier-fed river basins is impacting water availability for agriculture, leading to a decline in yields within some mountain areas, negatively affecting food security. Rural communities in high mountain areas, many of which face food insecurity, have traditionally depended on adequate soil moisture and on the timing of crop planting. Both factors are determined by the availability of irrigation water from glaciers and snowmelt, especially during the dry season. Consequently, a change in the cryosphere puts these communities at risk of food insecurity (Romeo *et al*., 2020). Irrigated agriculture downstream is also vulnerable to increasing variability in river flows within cryosphere-dependent basins, threatening food security for millions of people in the lowlands (Immerzeel *et al*., 2020; Hock *et al.,* 2019).

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[4] Glacial retreat has been observed since the mid-nineteenth century, albeit with occasional short-term glacier advances at different times and in different regions (Hock *et al*., 2019).

[5] Many low-elevation and small glaciers will lose most, if not all of their mass at global warming of 1.5 °C above pre-industrial levels. In tropical and mid-latitude mountains (the most populated areas), 50 percent ice volume will be lost under low-emissions scenarios and two-thirds to more than 90 percent under high-emissions scenarios by 2011 (baseline 2015) (Rounce *et al*., 2023). These findings were largely confirmed by a recent study that used 2020 as the baseline for glacier melt modelling analysis, concluding that annual global glacier volume loss is likely to increase under all climatic scenarios until 2035, reaching values expected to be 30 to 70 percent greater than present-day losses (Zekollari *et al*., 2024).

[6] Peak water refers to the point at which the annual runoff from glaciers reaches its maximum level. After this peak, the runoff begins to decline as the glaciers continue to lose mass (Huss *et al*., 2018).

At 96 years of age, Nicasia tends her llamas in Chile's Salar de Surire, where glacial waters sustain life now threatened by mining and climate change.

© Yeny Rodriguez Junco

Mountain hazards and the risks to societies are increasing due to changes in glaciers and other parts of the cryosphere, as well as climate change in general. Floods, including flash floods and glacial lake outburst floods, debris flows, landslides and avalanches, are the most common mountain hazards, affecting the highest number of people in mountain regions globally. These hazards also disrupt agricultural production, threatening food security and livelihoods in vulnerable mountain communities. The frequency and intensity of flood events are projected to increase in Central Asia, Northwestern South America, South Asia and the Tibetan Plateau. The number of glacial lakes has increased significantly since the 1990s, as glaciers have receded, and more proglacial lakes are expected to develop over the next decades, creating new hotspots of potentially dangerous hazards, primarily in the form of glacial lake outburst floods, which involve sudden releases of water and debris (Adler *et al.,* 2022).

Glacier and cryosphere melt and increasing river flow variability are also impacting water quality. This includes increased erosion and sediment loads in high mountain areas (Li *et al.,* 2021), changes in pH and temperature and shifts in nutrient concentration in mountain waters and downstream.[7] As glaciers recede, underlying trace metals may be exposed in some localities, which can detrimentally affect water quality, impacting agriculture and posing health risks to local populations. The release of heavy metals, particularly mercury and other legacy contaminants currently stored in glaciers and permafrost, is projected to reduce water quality for drinking water and irrigation (Hock *et al.,* 2019).[8]

Diverse agricultural practices play a critical role in protecting fragile mountain ecosystems. For instance, terrace farming, which is tailored to mountainous

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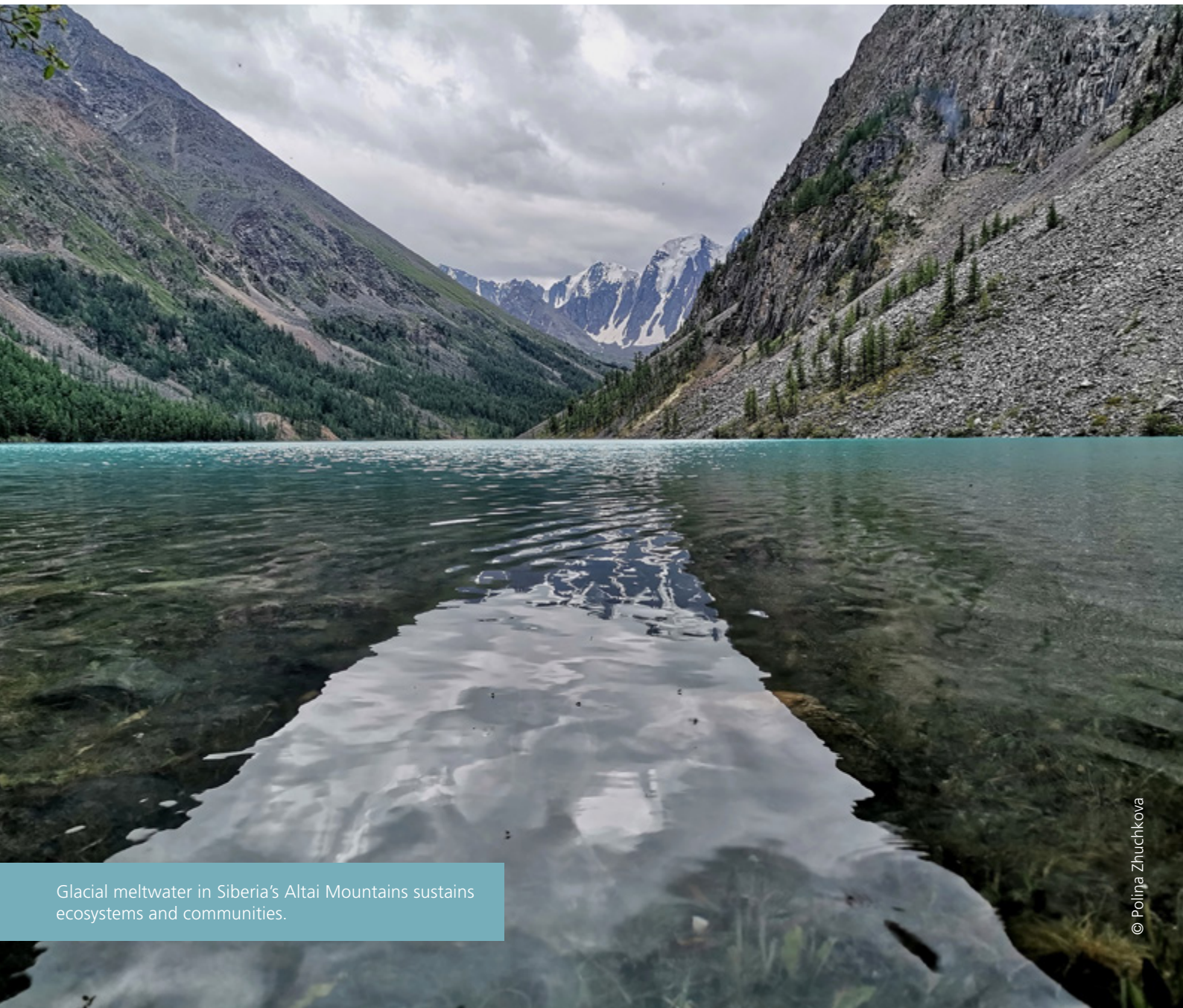
[7] Including dissolved oxygen concentration, nitrogen and phosphorus.

[8] Heavy metal threats are more focused where glaciers are subject to substantial pollutant loads, such as in Europe and High-mountain Asia, rather than in areas such as Alaska and Canada (Hock *et al.*, 2019). For example, an estimated 2.5 tonnes of mercury have been released by glaciers to downstream ecosystems across the Tibetean Plateau over the past 40 years (Zhang *et al.*, 2012).

terrain, improves water management, reduces soil erosion and preserves cultural heritage (FAO, 2022). Forests, which cover about 40 percent of mountain areas worldwide, protect against natural hazards by stabilizing steep slopes, regulating flows to groundwater, reducing surface runoff and soil erosion, and mitigating the potential for landslides and floods. Unsustainable tree cultivation can lead to increased soil erosion and reduced soil water infiltration. Forestry and agroforestry systems are important sources of livelihoods in mountains, providing essential environmental goods and services such as timber, fuelwood, carbon storage and other products that improve the lives of people living in mountains (UNESCO, 2025).

Glaciers are considered to be the abode of gods and spirits by many Indigenous Peoples in Asia, Latin America, the Pacific and East Africa and are the site of rituals and festive events that have been recognized in the UNESCO List of the Intangible Cultural Heritage of Humanity. The disappearance of glaciers would result in a substantial loss of cultural heritage and spiritual connection to the landscape and nature (IYGP, 2025).



Glacial meltwater in Siberia's Altai Mountains sustains ecosystems and communities.

© Polina Zhuchkova

International frameworks

Founded in 2002, the Mountain Partnership (MP) is the United Nations alliance of partners dedicated to improving the lives of mountain communities and protecting mountain environments around the world. The MP is a voluntary alliance of governments and organizations committed to working together with the common goal of achieving sustainable mountain development globally.

International Mountain Day has been observed since 2003 to highlight the importance of mountains for life on the planet. The Food and Agriculture Organization of the United Nations (FAO) is the coordinating agency for observance of the day. International Mountain Day 2025's theme 'Glaciers matter for water, food and livelihoods in mountains and beyond' is a contribution to the International Year of Glaciers' Preservation 2025, underscoring the importance of glaciers' preservation for agriculture, water security and the livelihoods of vulnerable mountain communities.

The declaration of the Five Years of Action for the Development of Mountain Regions (2023-2027) was a key outcome of the International Year of Sustainable Mountain Development 2022 (United Nations General Assembly, 2022a). Activities being implemented and planned for the period aim to enhance the international community's awareness of issues affecting mountain countries and to give new impetus to efforts aimed at addressing these challenges.

In December 2022, the United Nations General Assembly adopted a resolution proclaiming 2025 as the International Year of Glaciers' Preservation (IYGP) and 21 March of each year as the World Day for Glaciers, starting in 2025 (United Nations General Assembly, 2022b). The International Year and World Day aim to raise awareness of the critical role that glaciers, snow and ice play in the climate system and water cycle, while emphasizing the need to reduce greenhouse gas emissions to limit glacier melt. These two major events aim to promote global collaboration, strengthen scientific research and encourage policies and actions to protect glaciers and cryospheric systems (FAO, 2025b). The IYGP is co-facilitated by UNESCO and the World Meteorological Organization (WMO). As IYGP 2025 draws to a close, its key outcomes include enhanced scientific understanding, a stronger policy framework, increased awareness and collaboration, promotion of sustainable water management, preservation of cultural heritage and greater children and youth engagement. (FAO, 2025b).

Complementing the IYGP, the UN General Assembly has declared 2025–2034 as the Decade of Action for Cryospheric Sciences (United Nations General Assembly, 2024). Led by UNESCO, this decade will focus on advancing scientific research and promoting global climate action to address the impacts of a rapidly changing cryosphere.

The historic Ru Courtod canal in Italy's Aosta Valley channels glacier meltwater from Ventina to irrigate fields.

1

Glaciers and water nexus: glaciers' contributions to global freshwater

© Stefano Porta

Kagbeni village sits in the Kali Gandaki River basin in Nepal.

© Bijay Gurung

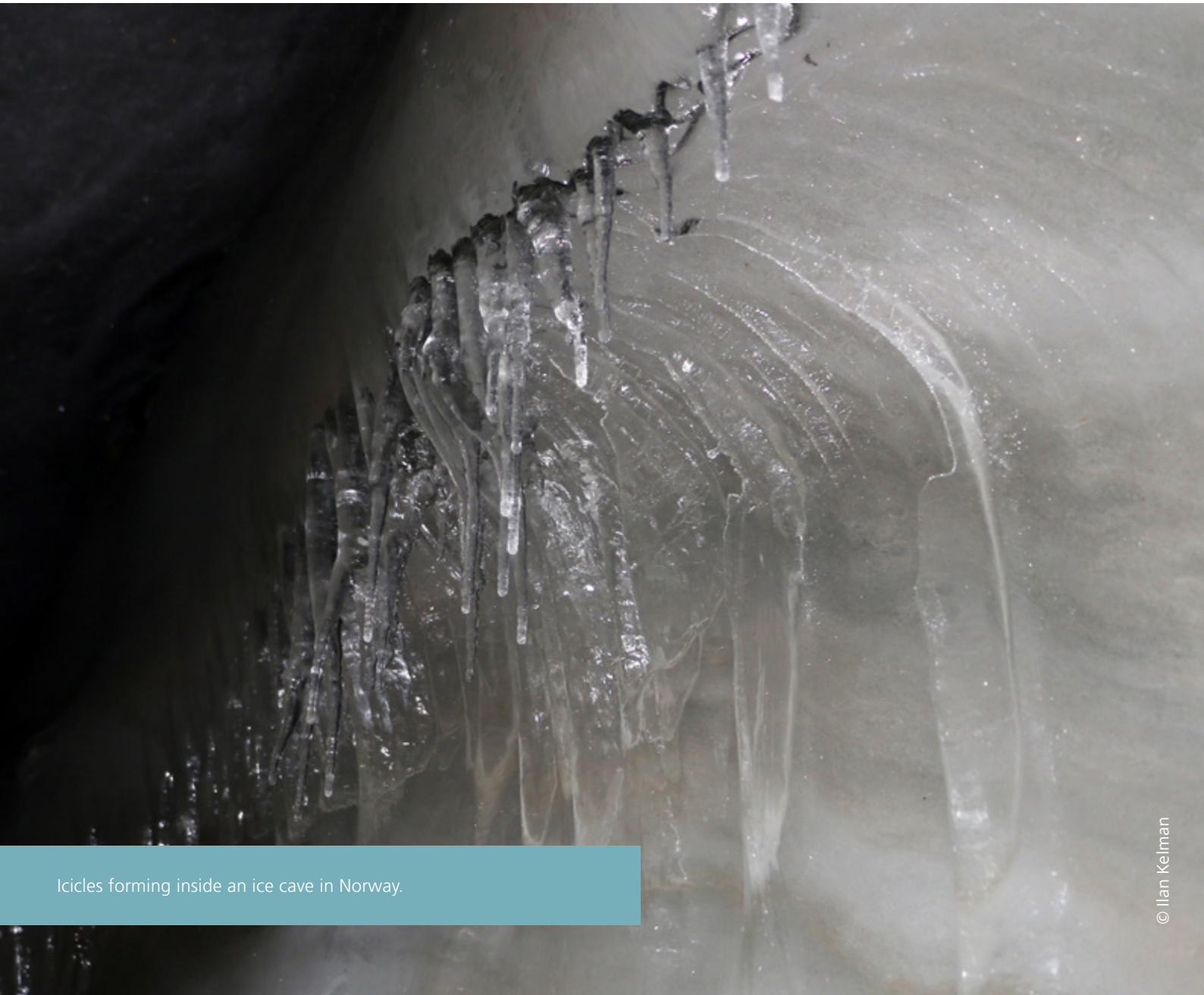
Glacial and snowmelt provide essential water supplies to rivers and basins at seasonal and annual timescales, both within and downstream from mountains (Adler *et al.,* 2022; Hock *et al.,* 2019). Changes in water flows pose a growing risk to the water, food and livelihood security of billions of people (UNESCO, 2025).

River basins with a large glacier and cryosphere (snow) component that are at high risk include the Amu Darya, Columbia, Fraser, Ganges-Brahmaputra, Indus, Po, Rhine, Rio Negro, Syr, Darya and Tarim. The impacts will be particularly felt in regions that strongly depend on glacier and snowmelt with pronounced dry seasons, including Central Asia, South Asia, tropical and subtropical western South America and southwestern North America (Hock *et al.,* 2019; Immerzeel *et al.,* 2020).

Key rivers that are heavily influenced by water sources from mountains (90 percent of the mean annual flow) include the Amu Darya, Colorado, Nile, Orange and Rio Negro. Rivers that depend on mountain waters for more than 70 percent of their flow include the Euphrates, Indus, São Francisco, Senegal and Tigris. Major cities that are critically dependent on mountain waters include Addis Ababa, Barcelona, Bogotá, Jakarta, Kathmandu, La Paz, Lima, Los Angeles, Melbourne, Mexico City, New Delhi, New York, Quito, Rio de Janeiro and Tokyo (Kohler *et al.,* 2015; UNESCO, 2025). Hotspot regions with large lowland populations highly dependent upon mountain waters include the Amu and Syr Darya, Brahmaputra, Colorado, Euphrates-Tigris, Ganges, Indus, Mekong, Niger, Nile, Pearl, Rhine, Yangtze and Yellow river basins (Immerzeel *et al.,* 2020).

Glacial melt provides an important source of water for seasonal buffering within mountains and downstream. During the dry season, meltwater from glaciers plays a vital role in supplying irrigated agriculture and drinking water. Glacial melt can act as a drought buffer**,** enhancing mountain and downstream resilience during periods of water scarcity (Adler *et al*., 2022).

Snowmelt accounts for most cryospheric contributions to streamflow in most river basins with a cryosphere component and is often substantially greater than glacier melt. The contributions of glacier melt to available water supply vary in importance. Snow cover has decreased in nearly all mountain regions, especially in spring and summer, with an expected further decrease in the coming decades. The magnitude and timing of snowmelt have already changed considerably, with trends in snow water equivalent being predominately negative around the world in the past few decades (Adler *et al*., 2022; UNESCO, 2025).



Icicles forming inside an ice cave in Norway.

© Ilan Kelman

Yaks, vital livestock for mountain communities around Ama Dablam, traverse the high trails of the Himalayas, Nepal.

© Gokhan Hisarciklilar

2

Glaciers and food nexus: glaciers' contributions to food security in mountain and lowland areas

Glacier-fed springs in Peru's Ayacucho region provide water, food and cultural continuity for mountain communities.

© Lourdes Diaz Espinoza

Mountains and glaciers are crucial for food security. Water originating from these high-altitude regions irrigates lowland farms and sustains the livelihoods of mountain communities. Sustainable agricultural practices and agrifood systems offer key solutions to food security and the climate crisis and are critical in preserving glaciers (FAO, 2025c). Agroforestry, agroecology, terrace farming, sustainable soil management and watershed management are some examples of agricultural practices which protect mountain ecosystems (FAO, 2024).

Glacial melt is an important seasonal source of water for irrigated agriculture in mountains, particularly in the dry season. There is evidence that a reduction in streamflow due to glacier melt or reduced snow cover has led to reduced water availability for the irrigation of crops, leading to a decline in agricultural yields in several mountain localities (Hock *et al.,* 2019). These include the Peruvian Andes, which have experienced reduced seasonal runoff due to glacier retreat that negatively affects crops (Bury *et al*., 2011), along with the high mountains of Asia (Rasul and Molden, 2019). For example, the Karakoram in Pakistan has experienced reduced seasonal water availability for irrigated crops due to glacial retreat and reduced snow cover (Nüsser and Schmidt, 2017). Conversely, in the Southern Andes, increased streamflow in the Elqui River in Chile, due to glacier retreat or changing snow cover, has led to increased water availability for irrigation and increased agricultural yields (Young *et al*., 2010). Reductions in snow cover can also affect agriculture through direct impacts on soil moisture. Rural communities depend on adequate levels of soil moisture at planting time,

often derived from irrigation dependent on glacier melt and snowmelt (Hock *et al.,* 2019). Reduced soil moisture has been reported in Nepal, where less snow cover has led to the drying of soils and lower yields of potatoes and fodder (Smadja *et al*., 2015; Hock *et al.,* 2019).

Pastoralism is an important livelihood strategy in many mountain regions. Changes in snow and glaciers are adversely affecting herders at their summer residences and winter camps, for example in the Himalaya (Namgay *et al.,* 2014) and Scandinavian mountain regions (Mallory and Boyce, 2018). Increased glacier meltwater has caused lakes on the Tibetan Plateau to increase in size, covering pasture areas and leading pastoralists to alter their patterns of seasonal movement (Nyima and Hopping, 2019). However, rising temperatures, with associated effects on snow cover, also have some positive impacts. Seasonal migration now starts earlier in Northern Pakistan and residence in summer pastures lasts longer (Joshi *et al.,* 2013; Hock *et al.,* 2019).

Globally, water from mountains makes a significant contribution to supplying irrigation in lowlands downstream. The contribution of mountain water to irrigation, however, varies according to different river basins and regions. Glacier and snowmelt contributions are particularly important in river basins where other blue water resources, such as lakes, rivers or groundwater, are scarce. (Viviroli *et al*., 2020).

Glacial meltwater provides an important source of water in the dry season for summer irrigation in downstream lowlands. It can reduce the variability of river runoff from year to year, in some cases at distances of hundreds of kilometres (Hock *et al.,* 2019). Lowland agricultural areas that receive irrigation water from rivers fed by glacier melt and snowmelt are projected to face negative impacts in some regions, due to reduced melt and runoff as glacial mass and snow cover decline over time (Hock *et al.,* 2019; Viviroli *et al.,* 2020). Changes in the onset of spring melt and peak snowmelt are predicted to alter the timing of irrigation water delivery downstream in the Hindu Kush Himalaya region and Central Asia (Hock *et al.,* 2019). Some areas of the Indus basin depend on glacier and cryosphere melt to supply lowland irrigation in the dry season (Biemans *et al.,* 2019).

Women in Bangladesh's hills walk miles to collect water from shrinking mountain streams.

© Monsurul Azam

Semitsvetnoye Glacial Lake in the Caucasus Mountains, Russian Federation.

© Mikhail Kapychka

Indo-Gangetic basin reliance on glacier meltwater for irrigation

Within the Indus River basin (Pakistan) during the pre-monsoon season, up to 60 percent of total irrigation withdrawals originate from mountain glacier and snowmelt, contributing to an additional 11 percent of total crop production. In some irrigated areas in the downstream Indus basin, over 50 percent of rice and cotton yields can be attributed to glacier melt and snowmelt. Although dependence on the floodplains of the Ganges is comparatively lower, meltwater is still essential during the dry season, particularly for crops such as rice and sugar cane. Based on data from 1981 to 2010, it has been estimated that 129 million farmers in the Indus and Ganges basins depend substantially on glacier melt and snowmelt for their livelihoods. Such melt provides enough water to grow food crops to sustain the diet of an estimated 38 million people.

Source: Biemans, H., Siderius, C., Lutz, A. F., Nepal, S., Ahmad, B., Hassan, T., Von Bloh, W., Wijngaard, R. R., Wester, P., Shrestha, A. B. & Immerzeel, W. W. 2019. Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nature Sustainability*, 2: 594–601. https: doi.org/10.1038/s41893-019-0305-3

Glaciers surrounding the Hunza Valley feed the Hunza River, Indus river basin, Pakistan.

© Christopher Wilton-Steer

Changes in water quality related to glacier and cryosphere melt have the potential to negatively impact agriculture in some mountain localities, where cryosphere melt makes a significant volumetric contribution to streamflow. This includes increased river sedimentation, leading to clogging of small-scale mountain irrigation systems and reducing efficiency; increased heavy metal concentration, leading to soil contamination and loss of productivity, with the potential for crop uptake and associated human health risks; and changes in nutrient concentration within mountain waters and downstream, impacting water chemistry, with implications for soil fertility and crop growth (Hock *et al.,* 2019).

Artificial ice reservoirs in Ladakh's Ursi village, India.

© Varuna Raina

Innovative adaptation measures conserve glacier meltwater for irrigated agriculture in the Indian Himalaya

In Ladakh, northern India, an estimated 90 percent of villages depend on glacial water for livelihoods and agriculture. Communities face critical shortages during the spring sowing season, when agricultural productivity is most vulnerable. Some villages also depend on glacial meltwater for drinking purposes. The storage of ice has a long history of providing water during the agricultural season. To cope with seasonal water scarcity at critical times for irrigation, such as the spring sowing season, villagers in the region have developed four types of ice reservoir: basins, cascades, diversions and a form known locally as ice stupas, first constructed in 2013 within Ladakh. These ice reservoirs capture water in the autumn and winter, allowing it to freeze and hold until spring, when it melts and flows down to fields. They retain a previously unused portion of the annual flow and facilitate its use to supplement the flow in the following spring. Increased irrigation frequency, yield, soil moisture and groundwater recharge are among the benefits observed. However, questions remain regarding ice reservoirs as a long-term adaptation strategy, as its operation depends on winter runoff and freeze–thaw cycles, both of which are sensitive to interannual variability. It also raises questions about the financial costs and labour requirements, which vary across the four types of ice reservoirs.

Acres of Ice is a social enterprise focused on addressing water scarcity in high-altitude regions, particularly in Ladakh, India. Between 2024 and 2025, Acres of Ice introduced Automated Ice Reservoir (AIR) systems in six Ladakhi villages. This innovative, nature-inspired technology uses temperature-sensitive automation and real-time monitoring to optimize ice formation while preventing pipeline freezing. From November to April, these systems stored approximately 18.34 million litres of water, significantly improving water availability. Funding from the Mountain Partnership Secretariat's Mountain Future Award 2024 supported an engineering fellowship that enhanced AIR system design and expanded applications to micro-irrigation, highlighting a scalable solution for climate-resilient water management in high mountain agriculture.

Sources: Nüsser, M. & Schmidt, S. 2018. Nanga Parbat revisited: Evolution and dynamics of socio-hydrological interactions in the Northwestern Himalaya. In: M.A. Fonstad, ed. *Mountains: physical, human-environmental and sociocultural dynamics*. London, Routledge. https://doi.org/10.4324/9781315158914; UNESCO. 2025. *The United Nations World Water Development Report 2025 – Mountains and glaciers: Water towers*. Paris. https://unesdoc.unesco.org/ark:/48223/pf00003930702025

Artificial glaciers help Kyrgyzstan meet water needs.

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Artificial glaciers help Kyrgyzstan to meet farmers' water needs

Kyrgyzstan, 94 percent of whose territory is covered by mountains, faces serious agricultural challenges. Access to water for irrigation and drinking is a challenge, particularly in the southern region where summer rains are scarce and winter snowfall is minimal. With rising temperatures and frequent weather fluctuations, the country is experiencing increasing drought, especially in highland pastures. To tackle the water scarcity, experts have turned to artificial glaciers as an innovative solution. As part of a pilot project 'Shared prosperity through cooperation in border regions of Kyrgyzstan and Uzbekistan', FAO provided technical support for the construction of seven artificial glaciers. These ice towers are created in winter by spraying mountain water into the air through vertical pipes, creating conical structures of ice, which freeze and gradually melt in summer, supplying a consistent flow of water. Each glacier can irrigate up to 500 hectares (ha) of land. This method is especially relevant as natural glaciers are retreating due to global warming. The success of the pilot project has inspired local communities to construct a further 40 artificial glaciers, many through collective efforts. In Batken region, southwest Kyrgyzstan, a joint FAO initiative with UN Women and the 'Roza Otunbayeva Initiative' Foundation, supported by financial assistance from the UN Secretary-General's Peacebuilding Fund, is being implemented. This initiative has helped to store more than 1.5 million m^3 of ice, enough to irrigate up to 1 750 ha through traditional furrow irrigation, equivalent to 2 451 football fields. Using modern techniques such as drip irrigation, the area was expanded to 15 000 ha. Research indicates that scaling this technology can support approximately 1 000 villages, serving their water requirements until 2030. Artificial glaciers promote climate-resilient agriculture, foster environmental and socioeconomic cooperation, restore ecosystems, support livestock farming and offer long-term protection against climate risks, while generating year-round income.

Source: FAO. 2023. *Artificial glaciers help Kyrgyzstan meet water needs. Food and Agriculture Organization of the United Nations*. Rome. https://www.fao.org/platforms/green-agriculture/knowledge/green-practices-repository/detail/artificial-glaciers-help-kyrgyzstan-meet-water-needs/en

In Peru, glacial waters sustain both biodiversity and the mountain communities that rely on them for their crops and livestock.

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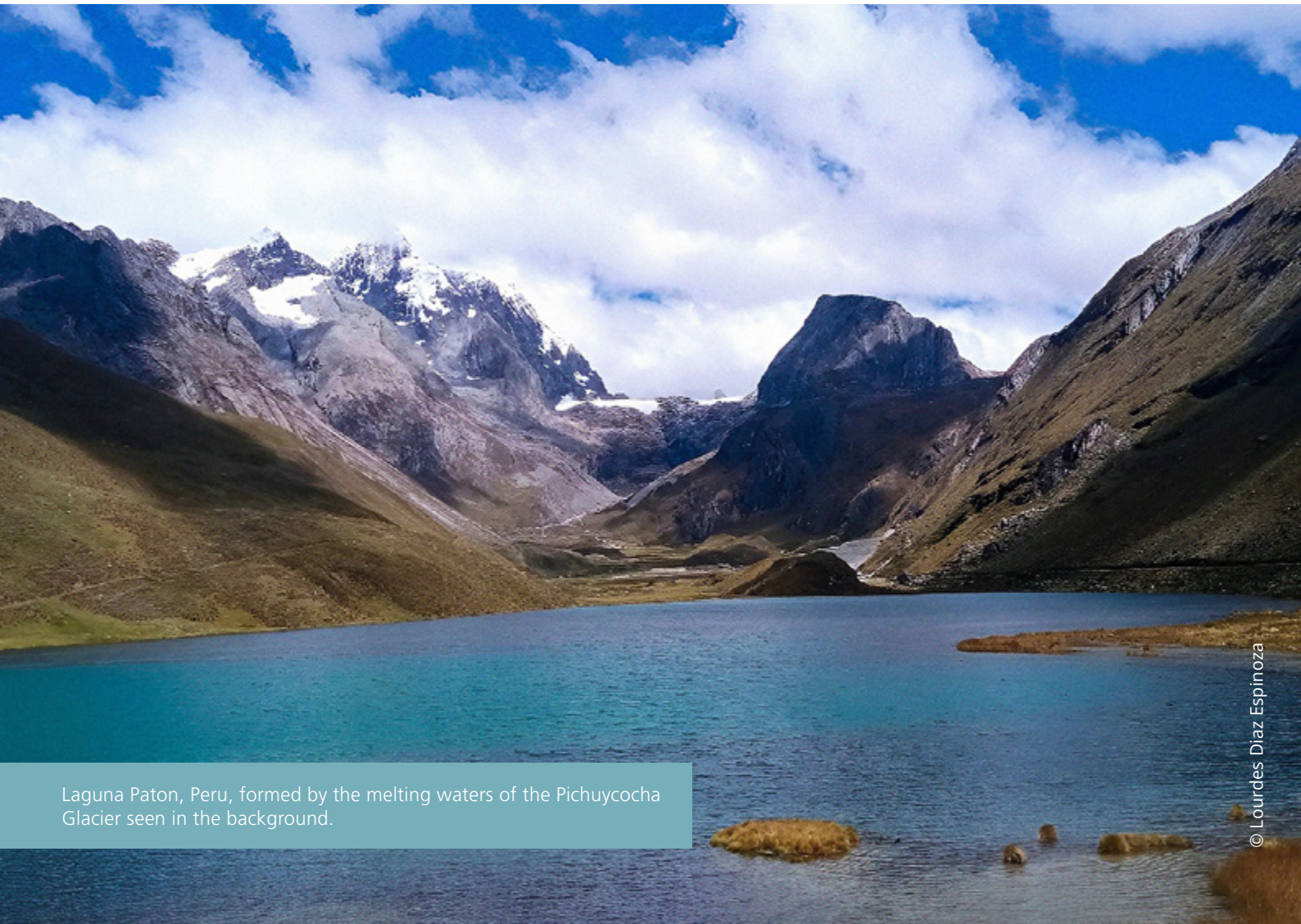

Laguna Paton, Peru, formed by the melting waters of the Pichuycocha Glacier seen in the background.

© Lourdes Diaz Espinoza

Traditional knowledge addresses deteriorating water quality from glacier melt in Peruvian Andes

As the Cordillera Blanc glaciers recede in the Ancash region of Peru, newly exposed rocks with pyrite in the bedrock are oxidizing, producing sulphates that are washed downstream and acidify the waters in the Qillcay basin. Monitoring of Shallap Lake within the basin has detected acidic waters and dissolved minerals such as iron, cadmium, arsenic and manganese. The deteriorating quality is affecting mountain communities that depend on the water for crops, livestock and drinking and is also impacting the water supply of Huaraz city downstream. In the small community of Canrey Chico within the Ancash region, a project – led by the Instituto Montaña, Santiago Antúnez de Mayolo National University and the Allín Yaku committee – has addressed the deterioration of water quality through a combination of new technologies and traditional knowledge. A natural filtration system has been installed within sedimentation pools where the minerals precipitate. The water is then channeled to flow slowly through a 5 km waterway, lined with native plants that catch and filtrate the metals, creating a favourable environment for bio-remediating bacteria, thereby mitigating the harmful effect of the minerals. The improved water quality allows it to be used for agriculture. Promising results have already encouraged its replication in other communities in the region that face deteriorating water quality due to receding glaciers.

Sources: Fortner, S.K., Mark, B.G., McKenzie, J.M., Bury, J., Trierweiler, A., Baraer, M., Burns, P.J. & Munk, L. 2011. Elevated stream trace and minor element concentrations in the foreland of receding tropical glaciers. *Applied Geochemistry*, 26(11):1792-1801. https://doi.org/10.1016/j.apgeochem.2011.06.003

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The Tuyuk-Su glacier in the Ile-Alatau mountains, Kazakhstan.

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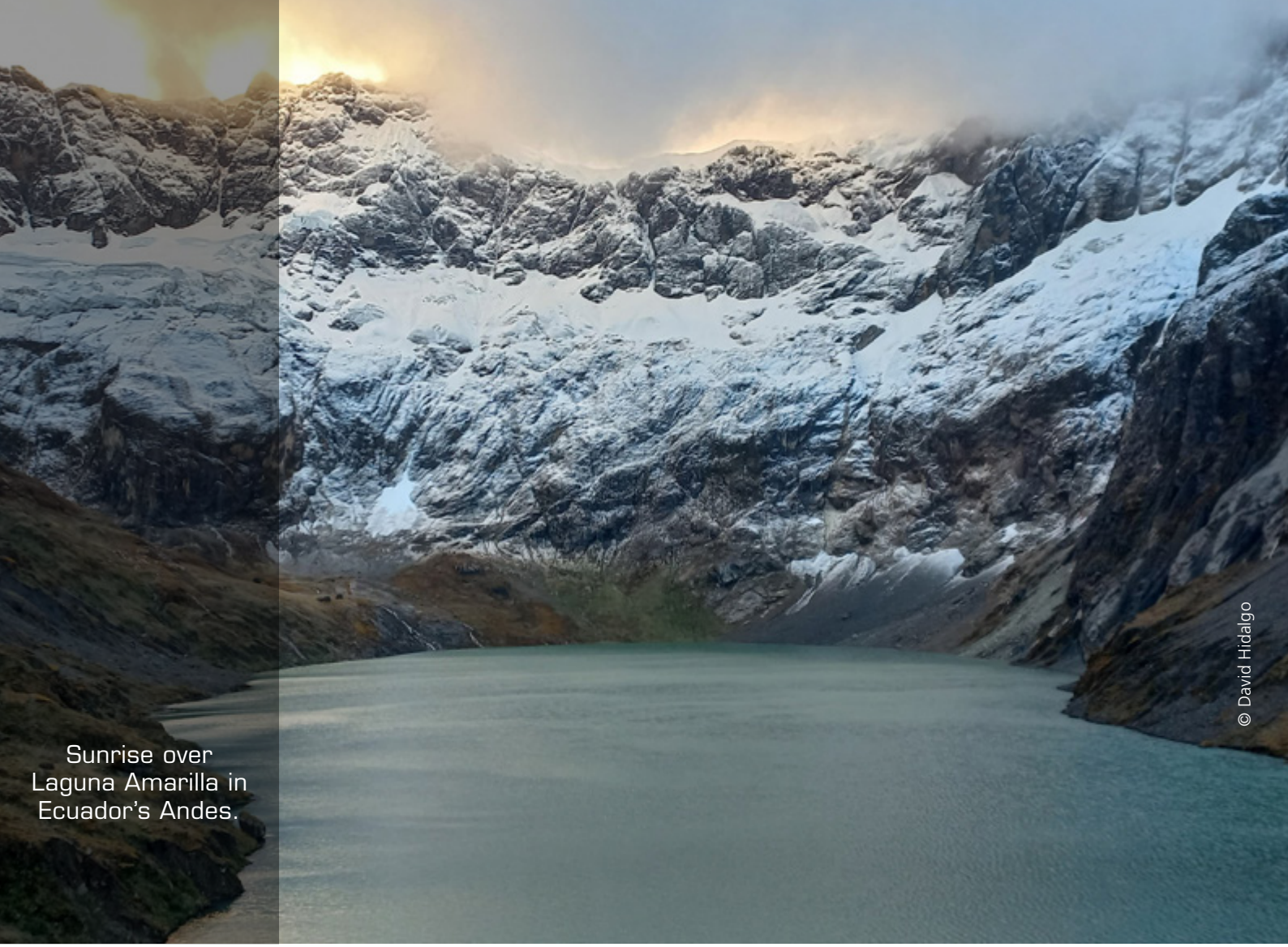
Policy recommendations



Sunrise over Laguna Amarilla in Ecuador's Andes.

© David Hidalgo

Policy recommendations to strengthen food and water security in mountains and downstream include:

- Enhance data and monitoring: Huge gaps remain in the monitoring of glaciers, particularly in high mountain regions. Improved observation coverage and resolution, data management and global data sharing can enhance analyses and prediction services that support timely actions to address threats, risks and impacts on water and food security. This includes establishing a global inventory of existing perennial ice and snow masses and of water quality aspects. Consolidating cooperation and partnerships among scientific institutions and relevant stakeholders involved in cryosphere monitoring and research is essential, including making research findings more accessible to all stakeholders. Strengthening of early warning systems, ideally based on real-time monitoring and data, is an urgent imperative (Adler *et al*., 2022; UNESCO, 2025). The reporting efforts under the Enhanced Transparency Framework of the Paris Agreement, and in particular the new targets for the global goal on adaptation (GGA), are expected to allow reporting against food, ecosystem and poverty targets, disaggregated by regions.[9]

[9] For further information, see UNFCCC, Global Goal on Adaptation – Background. https://unfccc.int/topics/adaptation-and-resilience/workstreams/gga#Background

- Adaptation and best practice in the agriculture sector: The current pace, depth and scope of water- and agriculture-related adaptation strategies are insufficient to address climate-induced risks and vulnerabilities. Strengthening knowledge development and management, capacity building, institutional support and funding is essential to promote robust and low-regrets adaptation to cryosphere-induced hydrological change, to ensure agricultural production and food security.[10] Inclusive governance structures and processes, including the design and implementation of adaptation policies and measures, can help to realize such capacity. Improving adaptive capacity will require addressing the root causes of vulnerability in mountains, which include poverty, marginalization, ecosystem degradation and inequitable gender dynamics. Acknowledging and respecting the many cultures and diverse local and Indigenous Peoples' knowledge systems in mountains, which form the backbone of community adaptive capacity, can create strong foundations for context-specific and integrated adaptation and mitigation strategies (FAO, 2017; Adler *et al*., 2022; UNESCO, 2025).

- Governance and policy: Mountains receive less attention than lowlands and are relatively absent from national, regional and global policy agendas. The management of mountain waters takes place primarily within country borders, through national legislation, policy and strategies. Despite their critical role in climate change adaptation, national climate policies and plans rarely recognize the unique challenges related to glaciers. For instance, while 57 percent of nationally determined contributions (NDCs) submitted by 1 January 2024 considered observed or projected climate-related impacts on freshwater-related ecosystem services (Crumpler *et al*., 2025), only a few include glacier-specific measures. Mountain countries have the opportunity to integrate mountain-related commitments in their NDCs, National Adaptation Plans (NAPs) and National Biodiversity Strategies and Action Plans (NBSAPs) to highlight climate and biodiversity action on mountains as key priorities. This prioritization can help to take advantage of funding mechanisms such as the Green Climate Fund, Adaptation Fund, Fund for Responding to Loss and Damage and Global Environment Facility.[11] Furthermore, national planning that involves both glacier and downstream countries would help promote long-term adaptation, resilience-building and vulnerability reduction efforts, along with risk management during extreme events such as landslides and glacial lake outburst floods (UNESCO, 2025).

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[10] Low-regrets adaptation refers to strategies or measures that provide benefits regardless of the severity or timing of climate change impacts. In other words, they are actions that are worth implementing even if the future climate risks are uncertain, because they produce positive outcomes under a wide range of possible scenarios.

[11] For additional information on relevant funding mechanisms and strategic frameworks, see Green Climate Fund (GCF). 2024. *Strategic Plan 2024–2027*. https://www.greenclimate.fund/about/strategic-plan; Global Environment Facility (GEF). 2024. *Draft GEF-9 Strategic Positioning and Programming Directions*. GEF. GEF/R.9/05. https://www.thegef.org/council-meeting-documents/gef-r-9-05; and UNFCCC. 2023. Consolidated list of indicator options, UAE-Belém work programme on indicators. https://unfccc.int/documents/647049

Glaciers sustain vibrant mountain communities in Puno, Peru.

© Gimi Cristian Mamani Ramos

- Transboundary governance: Since nearly all large rivers originate in mountain areas and are frequently shared among several countries, including cryosphere-fed rivers, transboundary water governance based on a watershed approach, or integrated river basin management, needs to carefully consider the significant benefits that mountains can provide to riparian countries. Regional cooperation among countries to foster transboundary landscape and river basin governance is an important mechanism for advancing sustainable development in mountains, including food and water security. Treaties or agreements can enhance cooperation through data and information sharing, help to fill gaps in human and institutional technical capacity and promote and foster dialogue and diplomacy (UNESCO, 2025). River basin organizations established for the transboundary rivers play an increasingly important role in ensuring holistic approaches to managing water, land and other natural resources from mountains to river mouths.

- Youth, Indigenous Peoples' knowledge and gender: Expanding and strengthening the meaningful engagement of children and young people in decision-making and policymaking processes at all levels can ensure greater diversity, inclusion and representation and encourage a willingness to think big, innovatively and with a long-term perspective (United Nations, 2023). Youth-led programmes, regional cooperation, inclusive governance, funding, education, innovation and Indigenous Peoples' knowledge can

drive long-term solutions. Youth-led initiatives and combining Indigenous Peoples' knowledge with science can guide policies on protected areas, sustainable land use and early warning systems. Mainstreaming gender in agricultural policies and plans, including risk and vulnerability assessment frameworks, is essential for inclusivity to build resilience and reduce food insecurity in mountain regions (UNESCO, 2025).

- Finance: Finance is a key enabler for enhancing agricultural production and promoting food security in mountains, thereby building resilience to cryosphere-induced hydrological change (UNEP, 2023). While substantial funding is potentially available for investment in sustainable development in mountain regions – including for agriculture – access to major support programmes has been relatively limited and underutilized (McDowell *et al*., 2020). Innovative and accessible international, regional, national and local funds should be mobilized to support water, agriculture and infrastructure investments. This should include increasing climate finance to support vulnerable mountains and downstream communities. Enhanced uptake of available support and funding could help to ease the burden for mountain communities and countries, for which the capacity and ability of actors to identify, access and mobilize resources need strengthening (UNEP, 2023).

- Sustainable agricultural practices: Agriculture accounts for more than 70 percent of global freshwater withdrawal (UNESCO, 2025). FAO emphasizes the need to further integrate sustainable agricultural approaches, to address challenges such as biodiversity loss, climate change and land degradation. An evaluation of the implementation of Conference Resolution 7/2019 offers a review of the integration of sustainable agricultural approaches, including agroecology (FAO, 2025a).[12] Promoting sustainable practices and agrifood systems in mountain areas is key, as they play a central role in regulating water flows, reducing surface runoff, limiting soil erosion and enhancing the infiltration and storage of water in soils and aquifers. Sustainable land management approaches can improve water retention in agricultural landscapes, while preventing soil degradation and downstream sedimentation and thereby reducing disaster risk (Romeo *et al*., 2021). Changing farming practices and diversifying livelihood strategies for smallholders and pastoralists is a common adaptation strategy in mountains. Examples of sustainable practices include terrace farming on mountain slopes, agroforestry, reforestation, contour farming, crop diversification and rotation, use of indigenous and resilient crop varieties, integrated pest management, livestock integration, water harvesting and conservation, soil conservation techniques and watershed management. Such robust and low-regret agriculture-focused adaptation measures have strong potential for managing the impacts of glacier and cryosphere melt (Alfthan *et al*., 2018; Adler *et al*., 2022).

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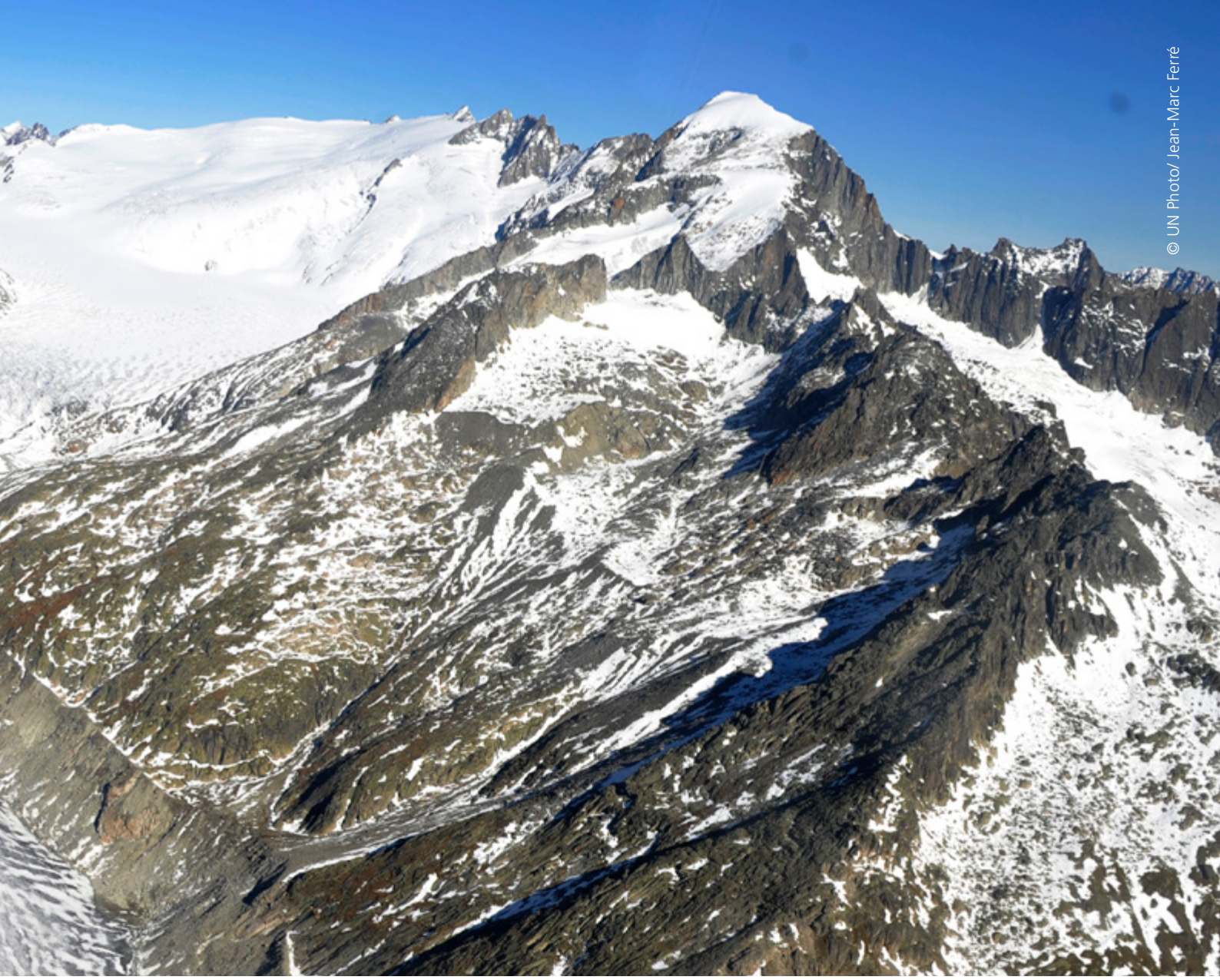
[12] The Programme Committee meeting 140/4 - *Evaluation of FAO's implementation of Conference Resolution 7/2019 "Further integration of sustainable agricultural approaches, including agroecology, in the future planning activities of FAO", including the balance of the full range of sustainable agriculture approaches and systems* – identified 13 sustainable agricultural practices: Climate-smart agriculture; sustainable pastoralism; organic agriculture; agroecology; sustainable land management; sustainable crop production intensification; ecosystem approach; integrated pest management; landscape restoration; conservation agriculture; integrated water resources management; regenerative agriculture; and agroforestry. For more information, see: https://openknowledge.fao.org/handle/20.500.14283/nq971en

Increased glacier melt in the Swiss Confederation due to climate change.

- Sustainable and integrated water resources management: Sustainable water management practices for mountain areas include rainwater harvesting, mountain spring rejuvenation and protection, wetland restoration, irrigation system infrastructure and efficiency improvements, as well as checking dams and percolation tanks/ponds to increase water storage and infiltration (Hock *et al.*, 2019; Adler *et al.*, 2022). Recent research in high mountain environments highlights that groundwater is increasingly understood to represent an important water source for streams, particularly during the dry season. Groundwater may therefore provide some resilience, at least temporarily, to glacier and cryosphere melt (Somers and McKenzie, 2020).[13] Initiatives to grow ice in the winter through artificial glaciers and ice stupas to augment early meltwater flows in the spring have also been attempted, with some success at small/local scales (UNESCO, 2025). Multistakeholder planning mechanisms such as National Water Roadmaps could be a way to support planning and implementation of integrated and sustainable water management.[14]

[13] In the longer term, groundwater recharge and contribution to streamflow are expected to decrease with ongoing climate change (Adler *et al.*, 2022).

[14] For further information on National Water Roadmaps, see *National Water Roadmap towards 2030 Agenda*. https://openknowledge.fao.org/server/api/core/bitstreams/6dd99d59-8950-4d31-a45a-b7a035a9daf8/content



- Integrated land-use planning: Promote integrated land-use planning (ILUP) as a mechanism to ensure balanced, efficient and sustainable use of natural resources across landscapes, fostering complementarity between mountain and lowland areas and among different sectoral land uses, including agriculture, forestry and water management. In line with the FAO *Guidelines for Integrated Land Use Planning*,[15] countries are encouraged to apply ILUP principles to coordinate cross-sectoral planning, optimize land and water use and harmonize ecological, social and economic objectives at multiple governance levels.

- Reducing greenhouse gas concentrations**:** Climate change mitigation in mountain regions can be supported through reforestation and wetland conservation, such as peatland restoration, as these areas offer substantial carbon storage and sequestration potential, with approximately 40 percent of mountain area covered by forests (FAO and UNEP, 2020; Adler *et al.*, 2022). In addition to storing carbon, mountain forests help to regulate water cycles, reduce surface runoff, stabilize slopes and limit soil erosion.

[15] The FAO Guidelines for Integrated Land Use Planning were presented at the 29th Session of the Committee on Agriculture (COAG) and will be presented for endorsement at COAG 30.

Box

Recommendations from the Dushanbe Glaciers Declaration

The following policy recommendations were made in the Dushanbe Glaciers Declaration, issued at the High-Level International Conference on Glacier's Preservation in May 2025:

- **Promoting scientific research and monitoring (and cooperation)** to advance glacier, polar ice and high mountain cryosphere science, including Indigenous Peoples' knowledge, technological innovations and monitoring systems aimed at understanding the dynamics of glacier retreat and its impacts on ecosystems, water resources and agriculture.

- **Addressing the socioeconomic impacts of glacier melting** to examine the downstream socioeconomic consequences of glacier retreat, including its effects on water availability, agricultural productivity and food security, hydropower and livelihoods.

- **Promoting integrated climate strategies** combining adaptation, mitigation and resilience: implement early warning systems, disaster risk reduction, infrastructure and nature-based measures to sustainably manage water resources, mitigate hazards from cryosphere decline and support resilient agrifood systems.

- **Promoting the participation of stakeholders,** including women, youth, local communities and Indigenous Peoples in glacier-related processes, recognizing the value of traditional and Indigenous Peoples' knowledge and that of local communities for sustainable agrifood systems.

- **Raising awareness and mobilizing resources** to increase global awareness of the importance of glacier preservation for food security, ecological balance and socioeconomic stability.

- **Catalysing actions** through key frameworks and partnerships to leverage key global frameworks, such as the 2030 Agenda and the Pact for the Future; also, strengthening partnerships across stakeholders to promote transformative action aimed at preserving glaciers through urgent climate ambition, as well as creating pathways for collective adaptation to the effects of glacier melt on local ecosystems, food security and human well-being.

Training modules from FAO

The preceding sections of this technical brief outline the critical challenges posed by accelerating glacier and cryosphere melt, underscoring the necessity for comprehensive adaptation strategies, including strengthening sustainable agriculture, water and management ecosystem-based adaptation approaches and practices. The FAO eLearning Academy offers two relevant online training courses developed by the Land and Water division at FAO, for policymakers, government staff, small-scale producer organizations and civil society organizations:

1. Agricultural ecosystem-based solutions can enhance production efficiency while simultaneously protecting and restoring the environmental resources' productive capacity. This course presents nature-based solutions and ecosystem approaches aimed at mitigating land and water degradation while enhancing food security.

2. Maintaining and restoring wetlands in agricultural settings examines the intricate relationship between agriculture and wetlands. Drawing on current knowledge, case studies and practical guidelines, the course provides actionable insights to harmonize agriculture with wetland conservation and restoration in a food systems context. It supports stakeholders in addressing wetland degradation, fostering sustainable agricultural practices and improving reporting on wetlands, contributing to the wise use and resilience of wetlands worldwide.

Group trek along the Nigardsbreen Glacier in the Breheimen National Park, Norway.

© Peder Kjaervik

Conclusion

The impact of glacier and cryosphere melt on agricultural production and food security is an issue that affects almost everyone. It has a direct impact on the millions of rural people living in mountains, half of whom are food insecure, as well as on the farming communities reliant on glacial melt and snowmelt for seasonal irrigation and during periods of drought. It also has an indirect impact on millions of people living downstream who rely on glacier- and cryosphere-fed rivers for irrigation and food security.

Mountain communities are especially vulnerable to increasing climate variability and a reduction in seasonal water availability for agriculture and irrigation. They often have no viable alternative water supply, resulting in loss of agricultural production and increased food insecurity. In many cases, this can lead to climate mobility. Similarly, downstream irrigated agriculture is vulnerable to increasing seasonal variability within cryosphere-fed river basins.

The implications of accelerating glacial and cryosphere melt, leading to increasing water variability, which in turn impacts agricultural production and food security for millions in mountains and downstream, are likely to increase in severity with further reductions in glacier/cryosphere mass in a warming world.

These changes will also have global economic impacts, affecting other sectors such as hydropower, tourism, trade and transport. Preserving glaciers is essential for environmental sustainability, economic stability and safeguarding cultural services, spiritual heritage and livelihoods.

When managed sustainably, mountain agriculture is not a driver of degradation but a solution, one that restores degraded ecosystems, safeguards soil and water, enhances biodiversity and strengthens the resilience of mountain communities. As such, agriculture is among the most practical and scalable solutions for sustainable mountain development.

The theme of International Mountain Day 2025 'Glaciers matter for water, food and livelihoods in mountains' is an opportunity to highlight the importance of glacier preservation for agriculture, water security and the livelihoods of vulnerable mountain communities.

The policy recommendations outlined in this brief offer an array of potential options for policymakers and practitioners to consider and apply to specific contexts.

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Glaciers are more than frozen landscapes — they are lifelines. Mountain glaciers and other cryosphere components are crucial for agricultural production, livelihoods and water and food security with about 70 percent of the Earth's freshwater existing as glaciers and ice caps.

Climate change is a major driver of cryosphere change, including the melting of glaciers. Mountain water flows are therefore becoming more uncertain and variable, affecting the quantity, timing and quality of water for agriculture.

When managed sustainably, mountain agriculture is not a driver of degradation but a solution, one that restores degraded ecosystems safeguards soil and water, enhances biodiversity and strengthens the resilience of mountain communities

This brief, published by the Mountain Partnership on International Mountain Day, is a contribution to the International Year of Glaciers' Preservation 2025 and it provides an opportunity to raise awareness about the vital role of glaciers and other cryosphere components both within mountain settings and downstream, and offers several considerations for policymakers and practitioners.

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